Source Considerations for Moderate Magnitude Earthquake Ground Motion Simulation Validation

Robin Lee[1], Brendon Bradley[1], Robert Graves[2], James Paterson[1], Jason Motha[1], Jonney Huang[1], Claudio Schill[1], Viktor Polak[1], Sung Bae[1]

[1]University of Canterbury, [2]USGS Pasadena

robin.lee@canterbury.ac.nz

1. Background and Objectives

Ground motion simulation validation efforts in New Zealand have previously been focused on large magnitude (M_w) earthquakes, such as the 2010 Darfield, 2011 Christchurch, and 2016 Kaikōura earthquakes, due to their significance for earthquake engineering applications, as well as small M_w earthquakes due to their relative simplicity and ubiquity which provided an opportunity to rigorously investigate systematic effects. This poster presents source considerations for moderate M_w earthquake ground motion simulation validation, which aims to bridge the gap between previous validation studies.

This study considers 75 moderate M_w earthquakes ($5.0<M_w<7.0$) with 2042 ground motion recordings across 220 stations, shown in Figure 1, and utilizes a 'Modified' Graves and Pitarka (2016) hybrid broadband ground motion simulation methodology. The simulation of moderate M_w earthquakes presents additional source nuances which are not apparent with small magnitude earthquakes and are therefore the focus of this study.

The LF component of the simulations use the NZVM (Thomson et al., 2020) to prescribe crustal velocity parameters for viscoelastic wave propagation. The HF component of the simulations use a generic 1D velocity model. The LF simulations are run with a finite difference grid spacing of 200m and a minimum shear wave velocity of 500m/s, yielding a maximum frequency of 0.5Hz. Measured V_{s30} values are used where available for HF empirical site amplification, otherwise values are taken from an interim update of the Foster et al. (2019) national V_{s30} model.

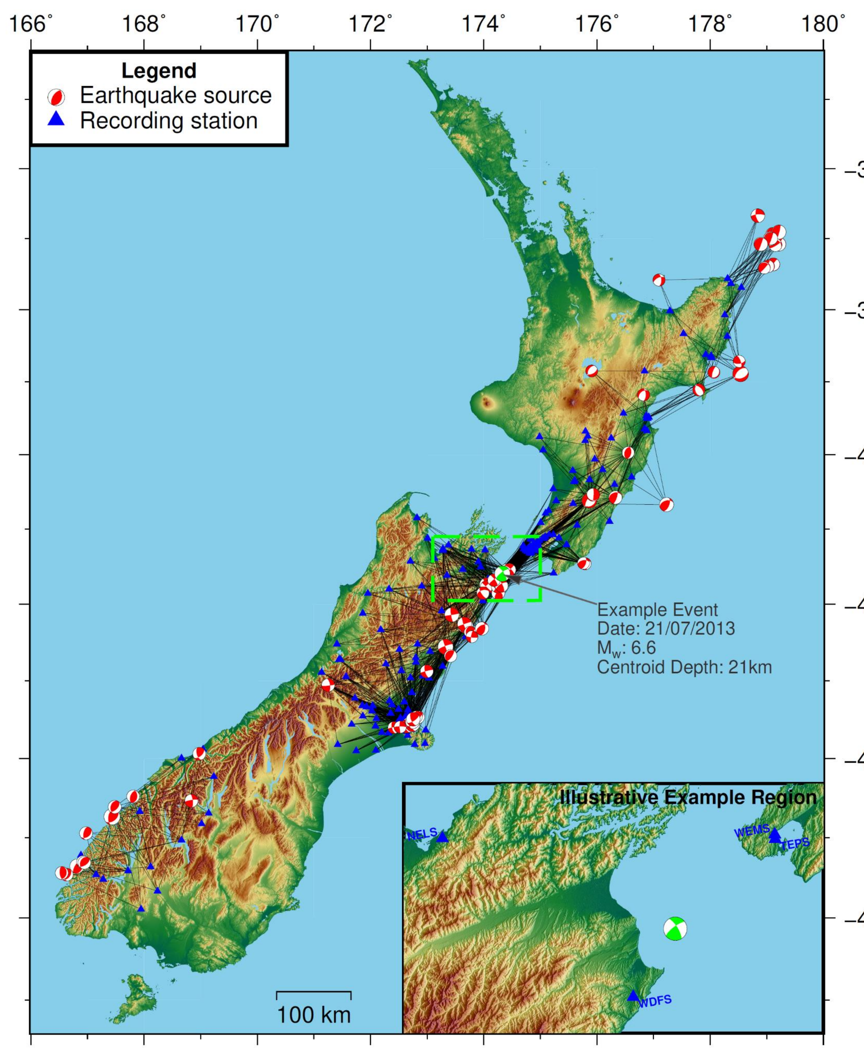

Figure 1: Map of New Zealand highlighting the 75 earthquake events, 220 recording stations and 2042 observed ground motion ray paths.

2. Kinematic Source Modelling

For moderate magnitude earthquakes, choices of source modelling assumptions can have significant impact on predicted ground motions as the rupture size becomes large. For comparison purposes, this study considers both point source and finite fault source models. Although point sources are likely not appropriate for moderate magnitude earthquakes at this regional scale, it is still informative and provides a benchmark for comparisons.

Two finite fault methods are considered which utilise the Leonard (2010) M_w-area scaling relationships (for rupture area and length-to-width aspect ratios) and various versions of the Graves and Pitarka (2010, 2016) kinematic rupture generator which produces spatially-variable slip, rise time and rake angle. These combinations are summarised in Table 1. Figure 2 provides examples of two finite fault models for the 21st July 2013 M_w 6.6 Seddon Earthquake (highlighted in Figure 1), one for each of the adopted finite fault modelling methods. Kinematic distributions differ between the two methods as the rupture generators have different randomization and spatial correlation algorithms. Method Finite Fault 2 also contains fault roughness which is not explicitly shown in Figure 2.

Table 1. Point source and finite fault source model parameters.

Method	M_w-Area Scaling	Slip Generator	Aspect Ratio	Fault Roughness	Figure
Point Source	Leonard (2010) for slip determination	N/A	N/A	N/A	N/A
Finite Fault 1	Leonard (2010)	genslip v3.3 (Graves and Pitarka 2010)	Proportional to L/W (Leonard 2010)	N/A	Figure 2a
Finite Fault 2	Leonard (2010)	genslip v5.4.2 (Graves and Pitarka 2016)	Proportional to L/W (Leonard 2010)	$\alpha = 0.01$	Figure 2b

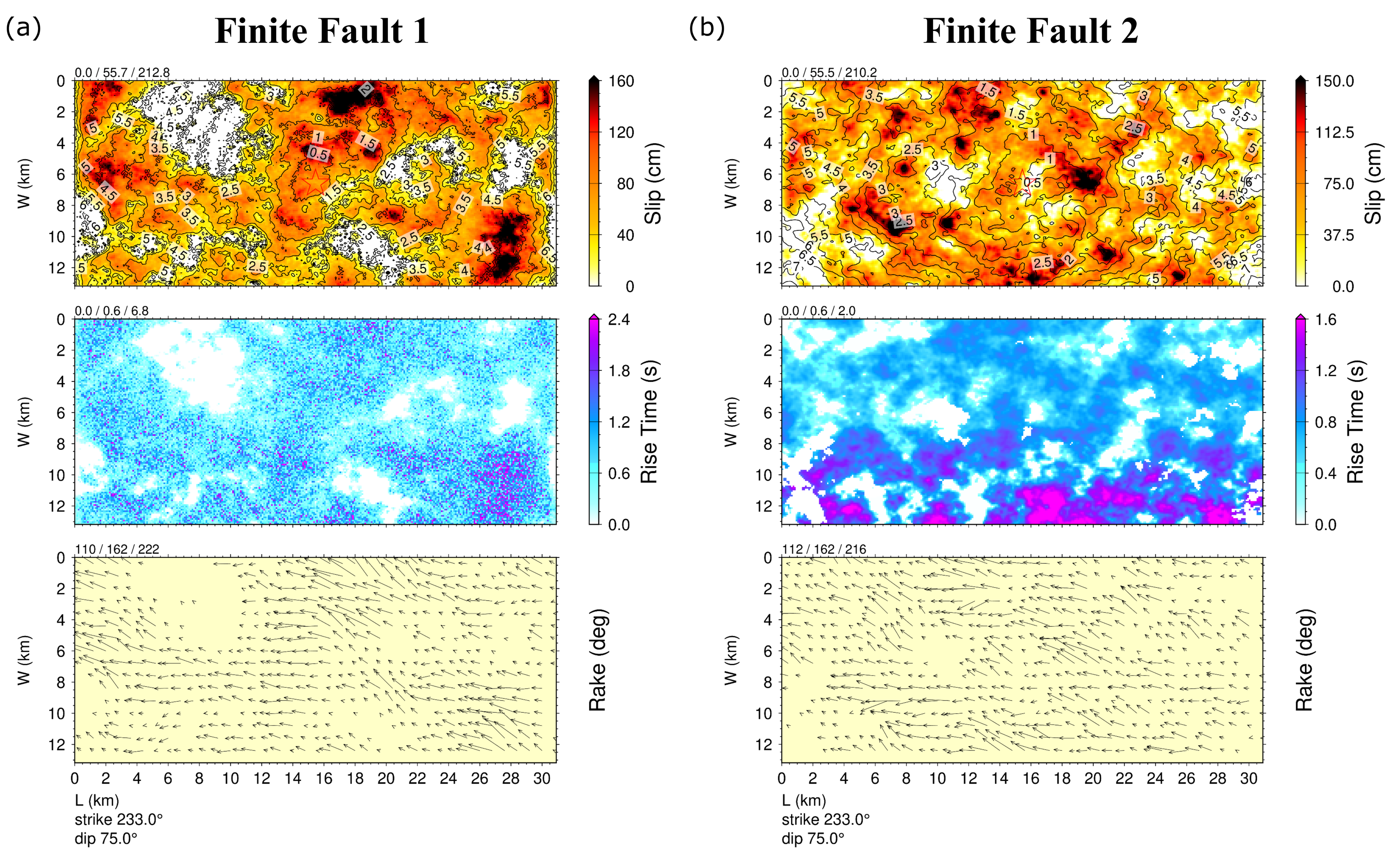

Figure 2: An example of finite fault geometry and kinematic rupture parameter distributions - slip, rise time, and rake angle – for the 21st July 2013 M_w 6.6 Seddon Earthquake using method: (a) Finite Fault 1; and (b) Finite Fault 2.

3. Illustrative Example Simulation

Ground motion simulations of the 21st July 2013 M_w 6.6 Seddon Earthquake are presented here to illustrate the salient attributes of the simulations. The simulations utilise the rupture models presented in the Kinematic Source Modelling section. Velocity waveforms are presented in Figure 3 for sites in Wellington, Nelson and Marlborough.

Overall, the point source simulation has stronger long period motion as a consequence of concentrated energy release in space and time. On the other hand, the finite fault simulations have energy release distributed over time and space resulting in lower peak amplitudes. The spatial randomisation of the kinematic source distributions would also contribute to uncertainty in the resulting finite fault simulation ground motions.

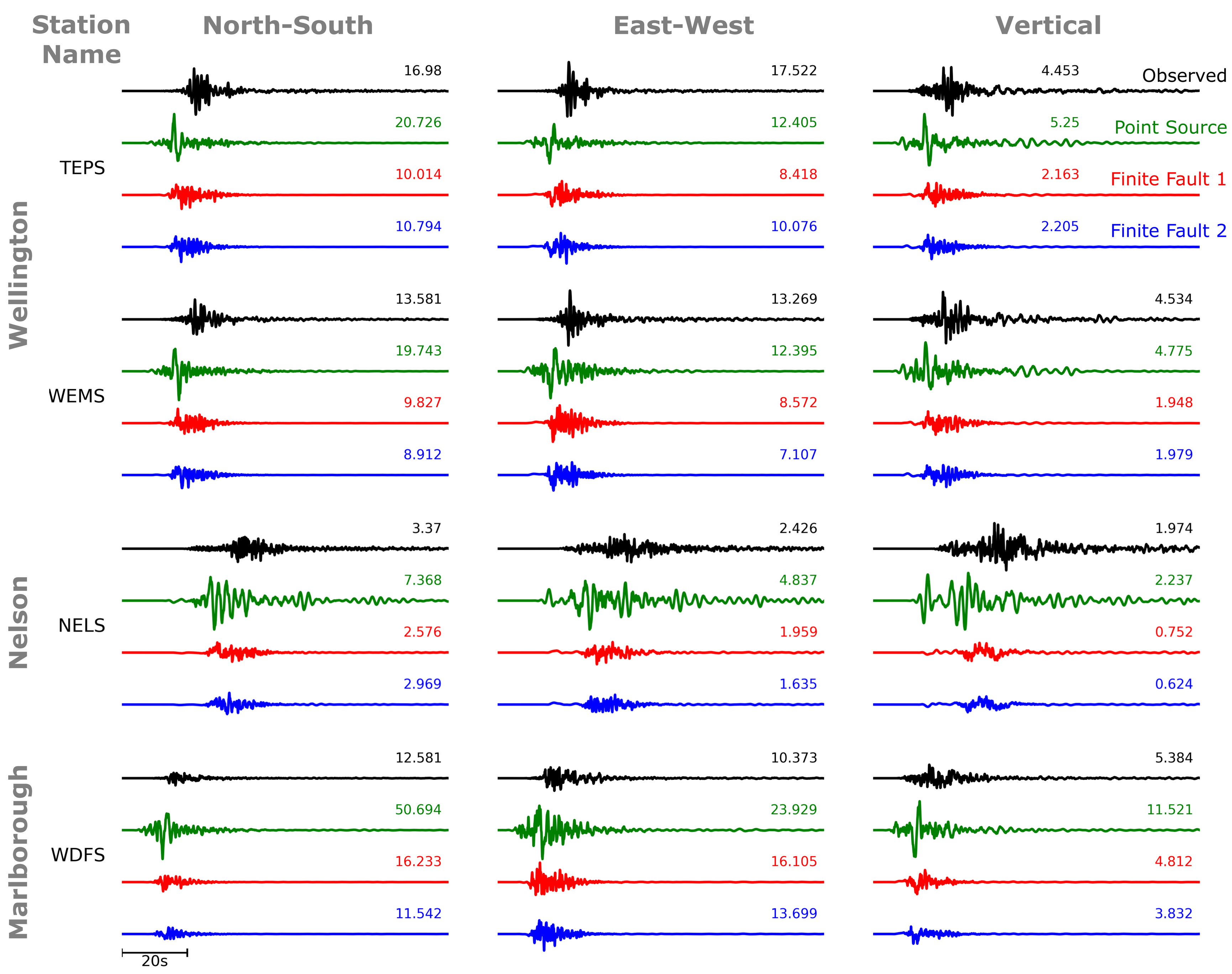

Figure 3: Observed (black), point source simulation (green), Finite Fault 1 simulation (red) and Finite Fault 2 simulation broadband velocity waveforms. PGV are provided to the right of each waveform in cm/s.

Figure 4 presents plots of PGA, pSA(3.0s) and D_{s595} as functions of source-to-site distance. The finite fault simulations tend to slightly underpredict PGA and D_{s595} while the point source simulation tends to significantly overpredict pSA(3.0s). Solid grey lines indicate median empirical predictions and dashed lines are their ±1 standard deviations.

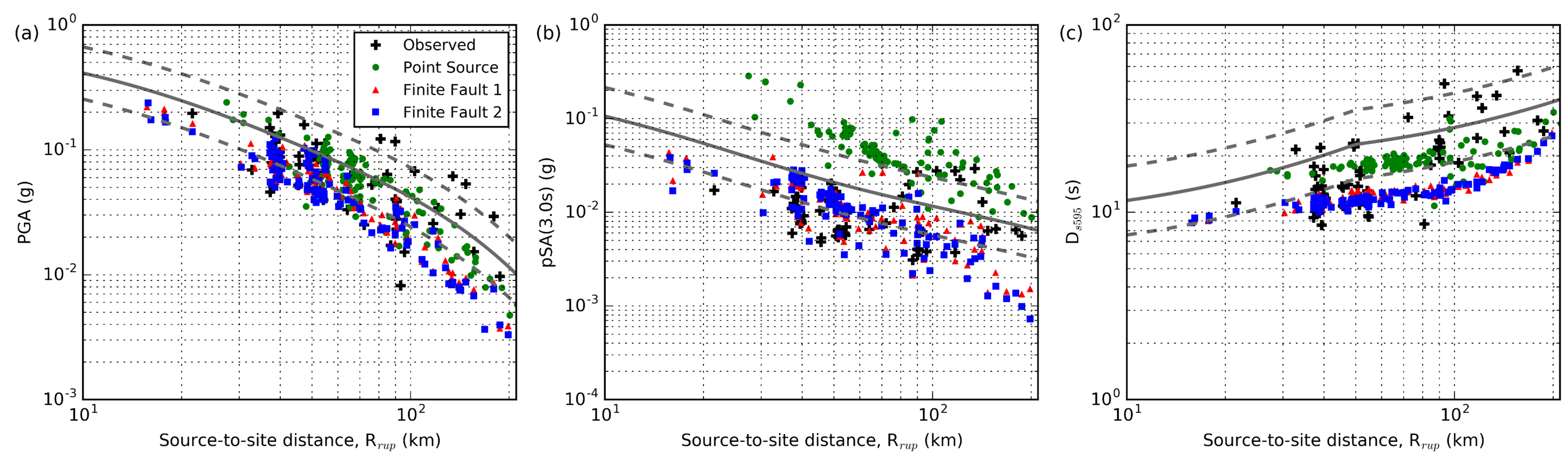

Figure 4: Observed and simulated intensity measures as a function of source-to-site distance: (a) PGA; (b) pSA(3.0s); and (c) D_{s595}.

4. Complete Dataset Analysis

Figure 5 presents the model prediction bias and total standard deviation considering all records across the sources and sites considered. The point source simulations are found to overpredict moderate-to-long period pSA while the finite fault simulations slightly underpredict at longer periods. The finite fault simulations have lower total standard deviation which arises from more appropriate modelling of the kinematic rupture.

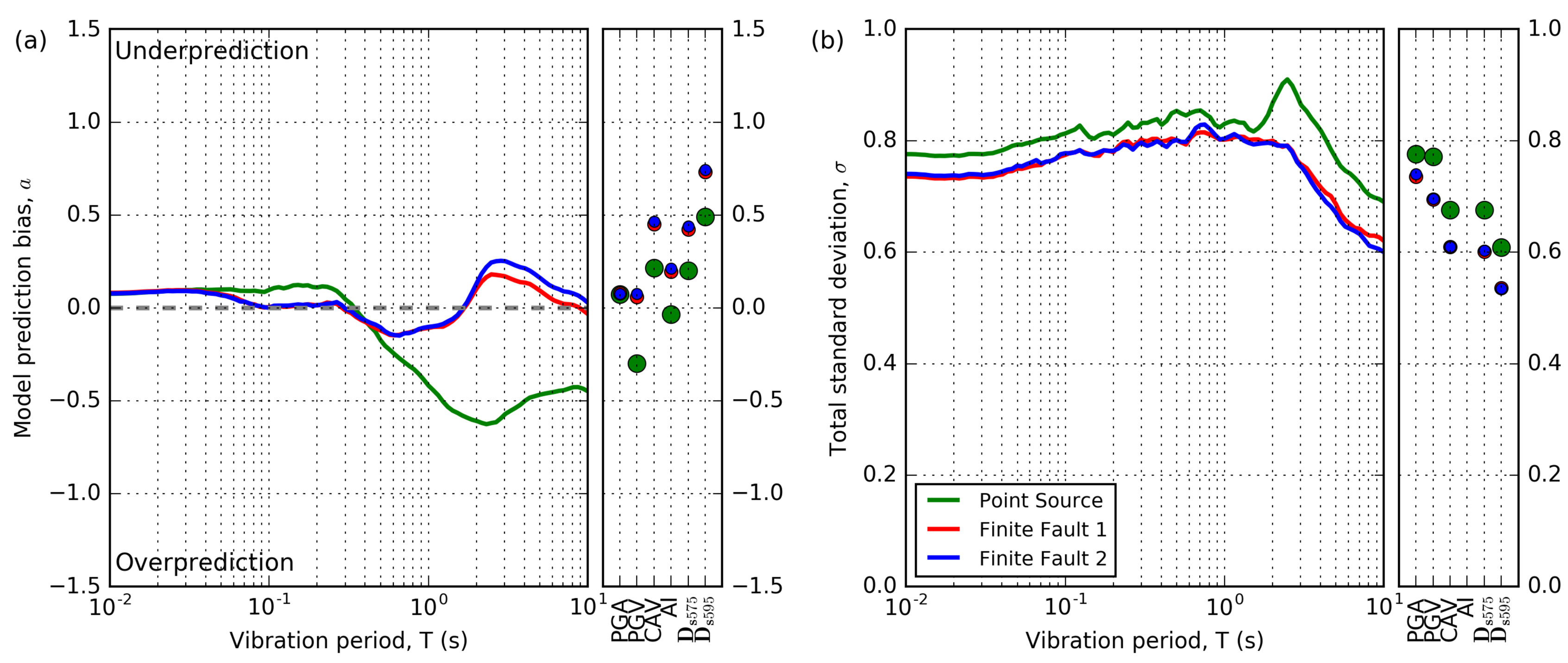

Figure 5: Ground motion model prediction summary: (a) systematic model prediction bias; and (b) total standard deviation.

5. Future Work

Future work will consider additional aspects of source modelling such as other M_w-Area scaling relationships and event-specific stress parameter. Simulations will also be run with higher resolution finite difference grid spacing which would better highlight the effect of fault roughness. As the kinematic rupture generators provide randomized distributions, several realisations of each earthquake will be necessary to obtain an averaged representation of the simulated ground motions.